TITLE
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The Bologna Key Project on ω Centauri

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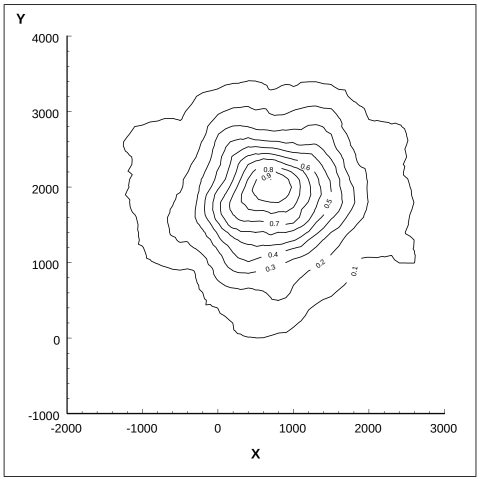
Abstract. In this contribution we schematically summarize a number of ongoing, coordinated spectro-photometric projects devoted to the study of the stellar population properties in ω Cen. All of these investigations are part of a global comprehensive project led by our team to address the complex formation history of stars in this cluster.

1. Introduction

After the recent discovery of a peculiar, extremely metal rich RGB population, we started a long term project devoted to the study of the multiple stellar populations in ω Cen. The global project consists of two main branches: *(a)* complete multi-wavelength photometric surveys to investigate the general properties of the sub-populations, from the far ultraviolet to the near infrared, using both wide-field and high-resolution imaging; *(b)* high and moderate resolution, high signal-to noise, extensive spectroscopic campaigns for giant and subgiant stars both in the optical and the infrared wavelength ranges. As a final result, we expect to completely characterize the abundance patterns, the dynamical properties and the relative ages of the sub-populations in ω Cen. A short description of some ongoing sub-projects is provided, along with some first preliminary results.

2. The Wide Field Photometric Campaign

The large field photometric campaign was performed in 3 different observing runs during 1999 and 2000 at the 2.2m ESO/MPI telescope (La Silla, Chile), equipped with the Wide Field Imager (WFI). We covered a large area ($33' \times 33'$) around the cluster and more than 230,000 stars were measured. The $(B, B-I)$ color



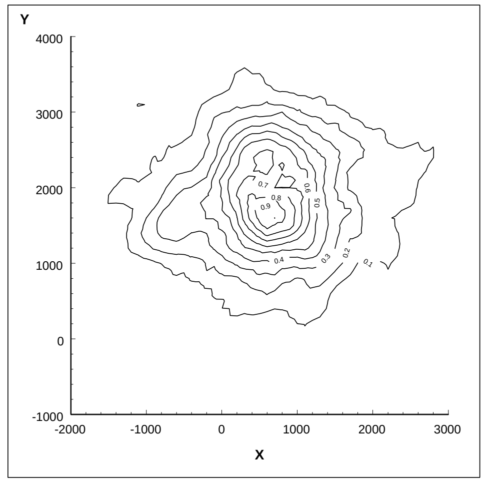


Figure 1. The spatial distribution for the RGB-MP (*Left Panel*) and RGB-MInt (*Right Panel*) populations are compared. The different elongations are well visible.

magnitude diagram (CMD) based on this dataset led to the identification of an anomalous Red Giant Branch (RGB) sequence (hereafter RGB-a) significantly redder and probably more metal rich than the bulk population in ω Cen (Pancino et al. 2000; Pancino, this volume). During the same observing runs we have also obtained U,V,H_α and R images which are now under analysis.

Following Pancino et al. (2000), three different sub-populations of red giants with different metallicities can be defined: *(a)* a metal poor population with [Ca/H]~ -1.4 (RGB-MP); *(b)* a metal intermediate one with $-1.1 <$[Ca/H]$<$ -0.5 (RGB-MInt) and *(c)* a metal rich, anomalous one with [Ca/H]~ -0.1 (RGB-a).

The spatial distributions for the RGB-MP and RGB-MInt populations are shown in Figure 1. As can be seen, the RGB-MP population shows the well known East-West elongation for ω Cen. The RGB-MINT one is instead elongated along the North-South direction, and shows complicated isopleths. Generalized (bidimensional) Kolmogorov-Smirnov tests ensure that the distributions of the two sub-samples are not compatible, suggesting that the two sub-populations have different dynamical properties.

2.1. The Tip of the Red Giant Branch

In a recent paper by Bellazzini, Ferraro & Pancino (2001), the photometric dataset by Pancino et al. (2000) was used in order to derive the RGB-Tip magnitude in ω Cen. The large number of giants measured in this cluster (more than 1700 in the brightest 3 mags) allows us to apply the same technique adopted by the HST key project on the extragalactic distance scale, obtaining $I^{TRGB} = 9.84 \pm 0.04$. Using the distance by Thompson et al. (2001) we obtained

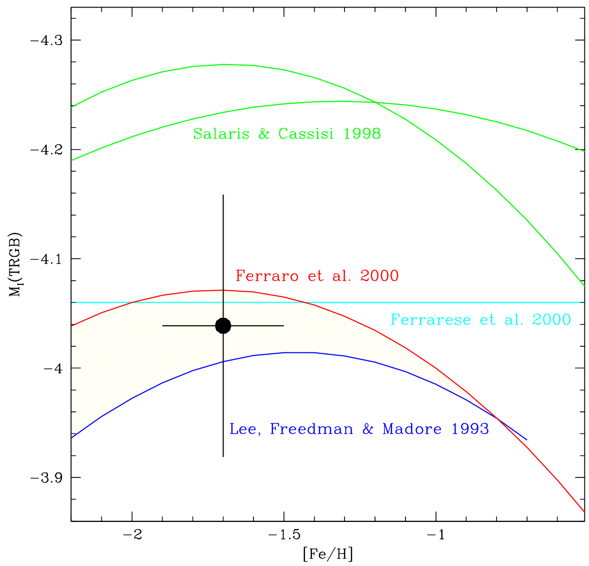


Figure 2. Our calibrating point for ω Cen (black dot), based on the recent detached eclipsing binary distance esimate by Thompson et al (2001) and on the photometry by Pancino et al. (2000), is compared with different calibrations for the RGB Tip method.

$M_I^{TRGB} = -4.04 \pm 0.12$. *This value represents the most accurate empirical anchor point for the calibration of the* M_I^{TRGB}*–[Fe/H] relation at [Fe/H]=–1.7.*

In Figure 2 this measure is plotted as a filled dot and compared with other empirical and theoretical calibrations. As can be seen, our value lies just in the region where most of the empirical relations lie (shaded area).

3. Infrared Photometry

A mosaic of 3×3 images in J and K was secured during an observing run at NTT (La Silla), with SOFI. The total field covered is roughly $\sim 13' \times 13'$ around the cluster center. Infrared photometry is especially important in deriving structural parameters of cool giant stars. In particular, combined optical-infrared colours such as $(V-K)$ are powerful photometric indicators of T_{eff}. A preliminary reduction of the central field ($5'\times5'$) has been already completed. Figure 3 shows the CMD for this region, obtained by combining the J and K with the V magnitude from the wide field observations. The mean RGB ridge lines of M 55 ([Fe/H]~ -1.81) and 47 Tuc ([Fe/H]~ -0.75) from Ferraro et al. (2000) are overplotted for reference. As can be seen from the figure, the existence of the RGB-a is confirmed also by this diagram: a few stars with metallicity similar to that of 47 Tuc are present to the right side of the main RGB.

4. The Spectroscopic Campaign

We are performing extensive spectroscopic campaigns of stars in ω Cen, with the following goals:

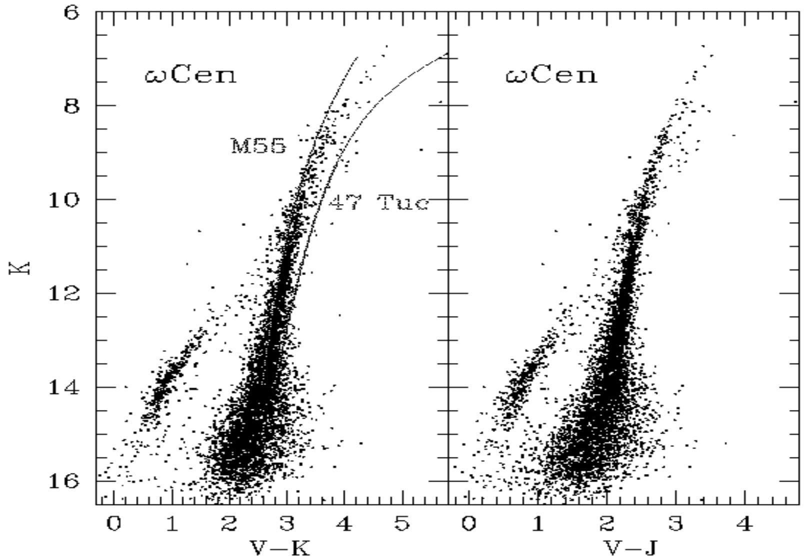


Figure 3. Preliminary results from the SOFI infrared photometry: the IR-optical CMD for the central region of the cluster is shown. The mean RGB ridge lines for M 55 and 47 Tuc from Ferraro et al. (2000) are overplotted for reference.

(i) To investigate the detailed chemical properties of the newly discovered ultra metal rich RGB-a.
(ii) To measure [Fe/H] and other iron peak elements abundances, and to assess membership of the RGB-a candidates.
(iii) To identify the major chemical contributors (SNeII, SNeIa, AGB stars) for the different sub-populations, by measuring α, r and s-elements abundances.
(iv) To look for CN-CH anticorrelations and to explore the effects of mixing, of the environment and of pollution from massive AGB stars.

In the following we schematically summarize the status of the ongoing spectroscopic surveys:

(1) High-resolution optical and UV spectroscopy of RGB and SGB-TO stars using UVES (UV-Visual Echelle Spectrograph) at the ESO VLT.

- RGB sample: a sample of 29 stars, belonging to the extremely metal rich, but also to the intermediate and the metal pooor RGB, has been already observed (see Figure 4). Preliminary results are presented in the contribution by Pancino, this volume.

- SGB-TO sample: we have been awarded 3 nights of observing time with UVES in march 2002, to study ~ 10 stars at the TO level.

(2) Infrared low and medium resolution campaign. The near IR spectral range is particularly suitable to study cool giants, due to the intrinsic sensitivity to low temperatures, and the background contamination by main sequence stars is

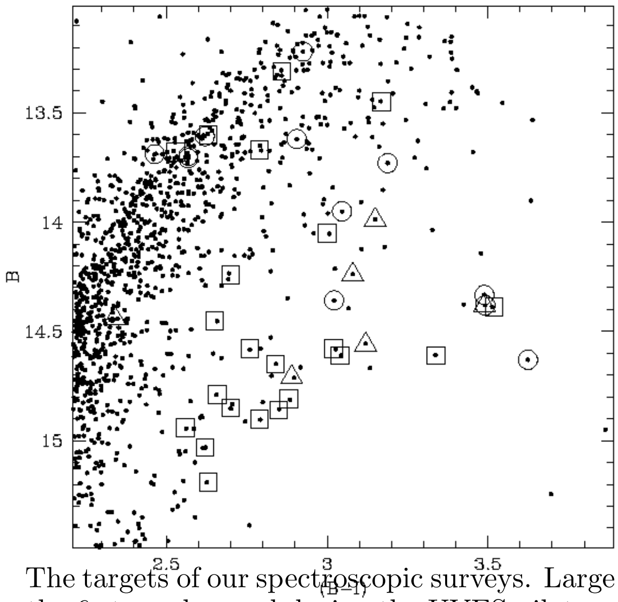


Figure 4. The targets of our spectroscopic surveys. Large open triangles refer to the 6 stars observed during the UVES pilot survey in june 2000. Large open squares refer to the 23 stars observed with UVES in apr–may 2001. Large open circles mark the 13 stars observed with SOFI in the IR.

much less severe than in the optical range, allowing to properly characterize the red stellar sequences also in crowded and/or metal rich environments. The near IR ($1 - 2.5\mu m$) spectra of cool stars show many absorption lines due to neutral metals and molecules. A reasonable number of these lines are strong, not heavily saturated and not affected by severe blending, hence they can also be measured at relatively low resolution and safely modeled under Local Thermodynamical Equilibrium (LTE) approximation. Thus, accurate abundances of key elements like iron, carbon (from the CO molecular bands), oxygen (from the OH molecular bands) and other α-elements can be easily obtained.

We already observed a sample of 13 giants at the NTT (La Silla, Chile) using SOFI (see Figure 4). Figure 5 shows four portions of the IR spectra (with a resolution of 7 and 14Å) for three RGB-a stars. Preliminary iron abundance determinations confirm that the RGB-a has a metallicity higher than [Fe/H]$\sim -0.8/-0.9$. In particular, the iron abundance for star ROA 300 nicely agrees with the results obtained with UVES.

5. The Relative Ages Problem

A fundamental step in order to understand the star formation history in this cluster is a precise measure of the ages differences among the different populations.

Figure 5. Four samples of the IR spectra for three RGB-a program stars are shown. Stars ST 21 and ST 51 correspond to stars ROA 513 and ROA 300 in the Woolley (1966) catalog. Some of the most prominent atomic and molecular features are marked.

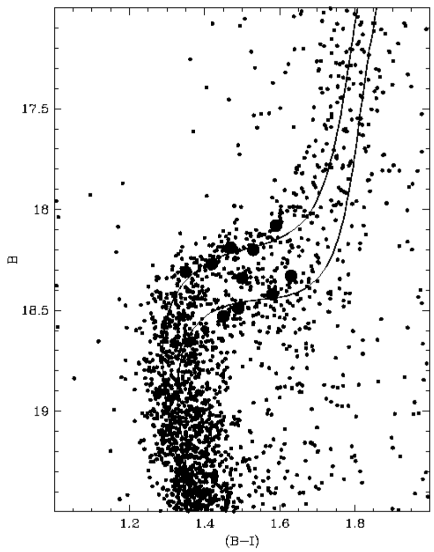


Figure 6. The SGB-TO region in the outer parts of ω Cen from the WFI dataset by Pancino et al. (2000). Targets for UVES high-resolution spectroscopy are plotted as large filled circles. The two lines represent isochrones with the same age (16 *Gyr*) and different metallicities ([Fe/H]=−1.7 and −1.3).

Thus, we are also performing a detailed study to investigate weather an age spread does exist among the various sub-populations in ω Cen. In order to measure *relative ages* we are collecting: *(a)* high resolution UVES spectroscopy of a sample of Sub-Giant Branch (SGB) stars in the outer region of the cluster, where two distinct SGB sub-branches can clearly be seen (Figure 6), and *(b)* high precision FORS1 VLT photometry of the central regions of the cluster, that in our previous WFI photometry are hidden by crowding. The entire data-set will allow us to disentangle age and metallicity, finally establishing *relative ages* of the sub-populations.

6. The Future Surveys with FLAMES

The Bologna Observatory is member of the ITAL-FLAMES consortium (a consortium of four italian observatories: Bologna, Trieste, Palermo and Catania) which participated to the construction of the FLAMES facility. The Fibre Large Array Multi Element Spectrograph (FLAMES) is a system that feeds with fibre links two spectrographs simultaneously, GIRAFFE and UVES, located on the Nasmyth platforms of VLT-UT2. GIRAFFE is a multi-object echelle spectrograph covering the entire visible range (370-900 nm) at intermediate (R=7500-12500) and high (R=15000-25000) resolution. FLAMES will therefore allow intermediate-high resolution spectroscopy for objects brighter than V=22 with

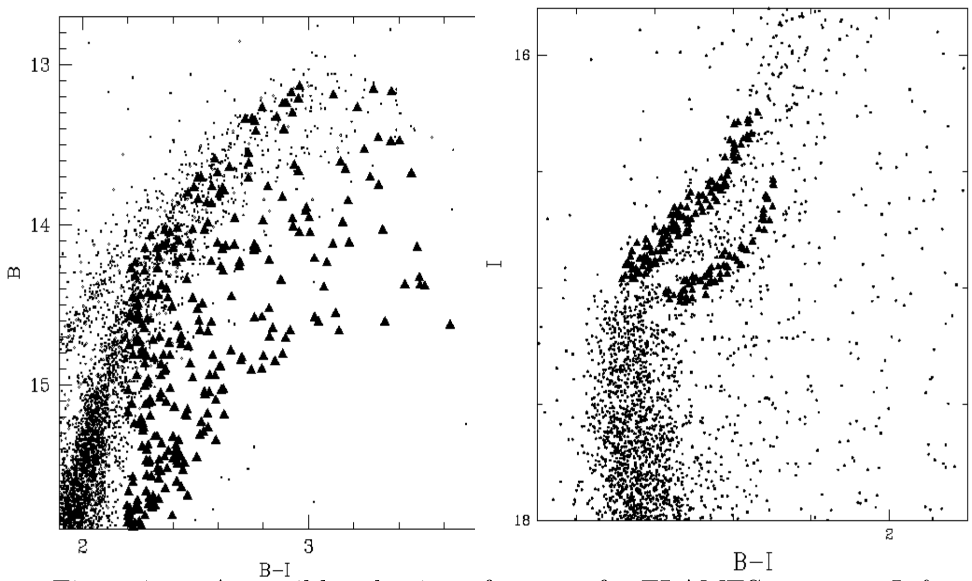


Figure 7. A possible selection of targets for FLAMES surveys. *Left:* the RGB survey. Some stars will be observed both with UVES and GIRAFFE for comparison. Many of our targets are chosen to be in common with previous published studies. *Right:* the SGB-TO survey. We plan to obtain a detailed chemical description of these stars to look for the counterparts of the RGB sub-populations and finally solve the relative ages problem.

a multiplex capability of 8 to 130 fibers over a large field of view (about 25 arcmin in diameter).

The use of this facility will allow us to make a significant step towards the final characterization of the different sub-populations in ω Cen, both from the dinamycal and chemical point of view. In Figure 7 we show a preliminary selection of candidates for the RGB (*Left Panel*) and the SGB-TO (*Right Panel*) FLAMES surveys.

We plan to use part of the Consortium guaranteed time to perform simultaneous observations with UVES and GIRAFFE. By mantaining an overlap of 5-10 stars between the high resolution ($R \sim 40000$) and the medium resolution ($R \sim 20000$) samples, we can check the performance of the spectral synthesis method used and avoid using blended or unreliable lines in the lower resolution spectra. An important byproduct of this massive spectroscopic survey is the production of an unprecedented catalog of radial velocity estimates. We will achieve a precision of 0.15 $km\ sec^{-1}$, that will enable us to explore the correlation between chemical and dynamical properties in the cluster stars.

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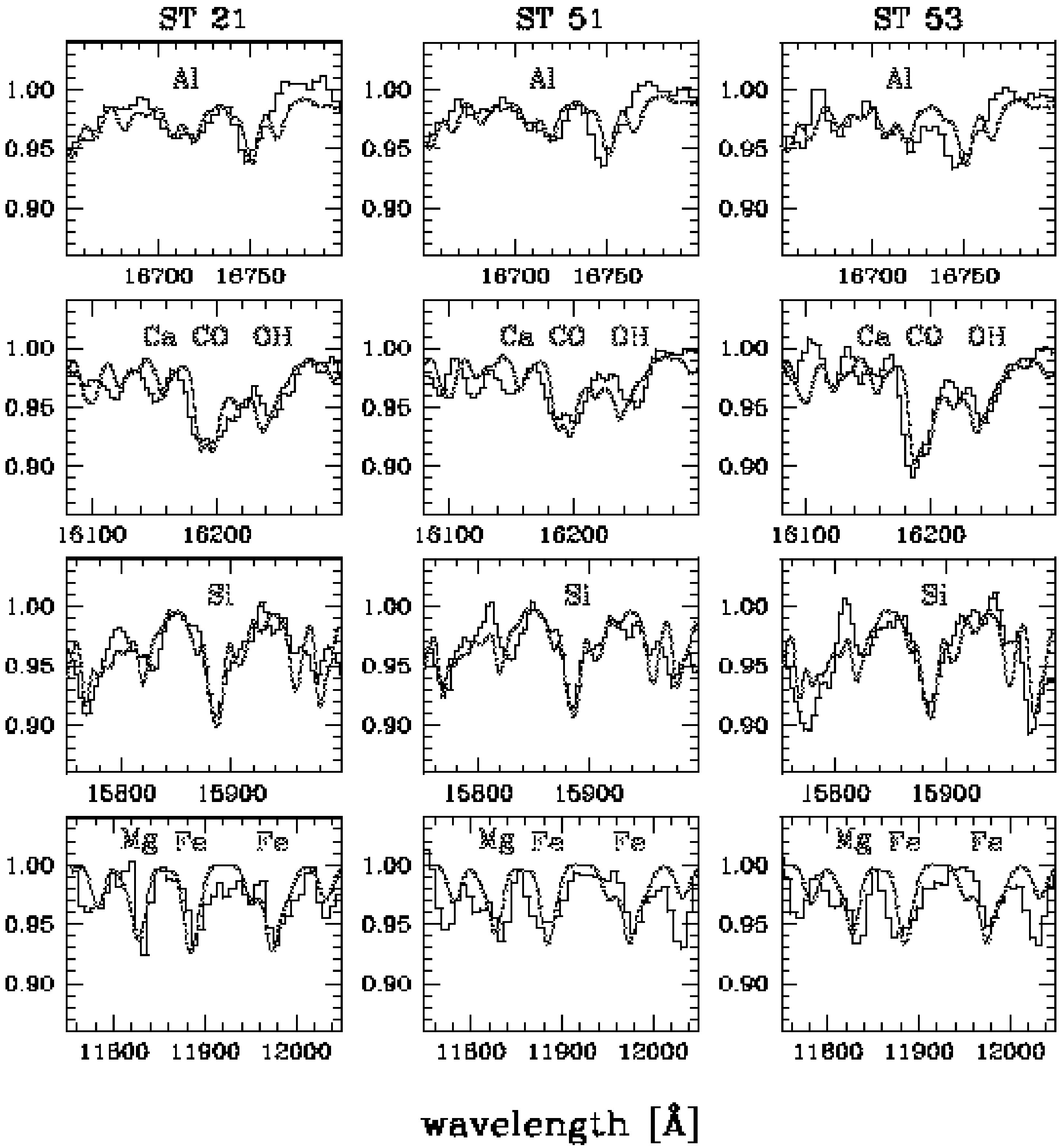
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